Detailed response to Reviewer 1

The authors thank the reviewer #1 for his/her fair and very constructive review of the manuscript. Considering the comments of the reviewers, some parts have been rewritten to clarify our objectives and results. Here is a detailed description of our responses to the review's issues. Reviewer comments are reported in red.

To help the reviewers, the revised manuscript has been provided in this file with major modifications highlighted in bold. The responses are referred in line numbers corresponding to this revised manuscript version.

General comments:

The added value of the satellite-derived PERSIANN precipitation product is assessed through the performance of a land surface model over a Spanish site. The evaluation of precipitation products is a particularly important and timely issue.

However, the objectives of this work are unclear.
The abstract as well as the introduction of the manuscript were rewritten.

The "Evaluation of PERSIANN" is rather disappointing as only few (one?) raingage stations are used and as no comparison with other gridded rainfall products is made.
A new comparison using all the available meteorological data over the VAS area and their nearest PERSIANN points was performed and introduced in the manuscript (Table 1 – page 18 and Fig. 2 – page 23). A comparison of these satellite rainfall estimates with interpolated rainfall product representative over 10x10 km² was also performed (Fig. 4 – page 25).

I don't see why SMOS should be mentioned in the title as no real nor synthetic SMOS data are used. Similarly, I could not perceive any SMOS CAL/VAL activity in this study.
During SMOS Cal/Val activities, the instrument measurements have to be validated. For this purpose we must have a continuous field of soil moisture over an area slightly larger than the actual pixel (3dB footprint) so that we can convolute the antenna pattern on it. To make such a large field of soil moisture ground measurements are not tractable so we rely on a limited set of ground sites and spatialize the soil moisture information with use of a SVAT coupled to a set of forcings and a very good knowledge of soil types and land use. At SMOS pixel scale (50x50 km²), having an accurate estimation of the amount and temporal/spatial distribution of precipitation is a critical issue so as to have a faithful representation of the soil moisture distribution. As in situ observations are not always available, the use of a satellite rainfall database is needed. In this framework the PERSIANN database was evaluated so as to be use as input to a SVAT model. Once the soil moisture fields are known, it is possible to compute satellite level brightness temperatures (to check calibration for instance) or to compare to satellite products. Moreover, as the model runs with a reasonably fine time step we can always have values at the time of overpass. This study is the necessary step towards simulating SMOS brightness temperature. Moreover VAS data are part of the CAL/VAL activities.

For the title, we intend to ask for the possibility to change it into: "Soil moisture modelling of a SMOS pixel: interest of using the PERSIANN database over the Valencia Anchor Station.".

The English is rather poor. This indicates that this paper was written too rapidly and without sufficient verification of editorial issues by the authors.
An effort was made to improve the quality of the English used in this manuscript.

This study gives little clue about the added value of PERSIANN, as the only given scores concern simulated surface soil moisture, with no independent verification of the simulated soil moisture (e.g. in situ observations). The accuracy of soil moisture simulated by a land surface model is not a direct measure of the quality of the precipitation used to drive the model. Indeed, many physical processes simulated by the model influence the soil moisture simulation, generating uncertainties and errors. Do the authors assume that their model is "perfect", after the calibration performed by Juglea et al. HESSD, 7, 649-686, 2010, for SURFACE soil moisture ? But even so, surface soil moisture is probably less sensitive to the quality of the estimates of precipitation amount than the root-zone soil moisture. Surface soil moisture is a good indicator of the occurrence of rain but has less connexion to the magnitude of the rainfall events (as opposed to root-zone soil moisture).
A comparison with ground measurements was introduced in the manuscript (see paragraph 4.2.1, L294).

The comparison with AMSR-E data performed in this paper is, again, purely qualitative.
The remote sensing soil moisture products available until now are obtained from different satellites which are not perfectly adequate to measure the soil moisture (too high in frequency for instance). In our case also, as the AMSR-E soil moisture values were not in good agreement with in situ measurements/simulated data the comparison was done in normalized values. AMSR-E data were used to check the temporal variation of soil moisture and so to observe the evolution of the spatialized soil moisture at high scale.

Finally, it seems that the existing literature is not sufficiently cited (e.g. evaluation of AMSR-E products, LSA-SAF products, global precipitation products, : : :).
New references concerning the application of satellite rainfall products in hydrological models (L70 – L78) as well as references concerning the evaluation of AMSR-E products (L88) were added in the text.

This paper cannot be published in HESS in the present form.

Particular comments:

- P. 1144, L. 6-8: "the Valencia Anchor Station (VAS) experimental site, in Spain, was selected to be one of the main test sites in Europe for the SMOS Calibration/Validation (Cal/Val) activities". Is this site really suitable for the SMOS CAL/VAL (RFI problems in Spain have been extensively described and commented on the CESBIO web site) ?
You are right. After launch, SMOS had detected a significant amount of RFI sources over the globe. Among those sources, some of them are located in Spain, affecting the VAS test site. However, the Spanish authorities concentrate their efforts and already managed to stop most of

these sources. These news are reported on the SMOS-CESBIO blog (http://www.cesbio.ups-tlse.fr/SMOS_blog/). So ESA is still considering the VAS site as a key site for the Cal/Val, and our work has their support. Moreover, recent analyses of the brightness temperature over VAS reports values within the expected range.

- P. 1145, L. 6-8: PERSIANN is not the only global gridded precipitation product. Why using PERSIANN only? Why not comparing PERSIANN with other products (e.g. GPCC, GPCP, ERA-Interim,: : :) ?

Many studies and programs which evaluate different satellite precipitation products over various regions exist. Our purpose is to use this satellite databases as input of a hydrological model to improve the soil moisture modelling in situations where there are few or no rain-gauge data. The choice of PERSIANN-CCS estimates is because there are among the satellite rainfall databases with the highest spatial (0.04x0.04°) and temporal (1 hour) resolution.

- P. 1146, L. 4-5: the accuracy of soil moisture simulated by a land surface model is not a direct measure of the quality of the precipitation used to drive the model.

No, you are right but meanwhile it plays an important role. Precipitation is considered as an important factor in controlling spatial and temporal patterns of soil moisture (Grayson et al., 2006). As over the studied area an adequate gauge network in not available, one possibility is to use the soil moisture to evaluate this satellite rainfall estimates.

- P. 1146, L. 25: what do the authors mean by "fully equipped meteorological stations"?

Fully equipped stations provide all the classic weather measurements: air temperature and humidity at screen level, atmospheric pressure, precipitation, wind speed and direction and solar and atmospheric radiation. The information was added in the text L106 - L109.

- P. 1147, L. 5-7: "The shortwave was extracted from Meteosat, a geostationary weather satellite launched by the European Space Agency (ESA)": what do the authors mean by "shortwave" ? Downwelling shortwave radiation ? What is the origin of this input ? Have the authors generated this quantity themselves? Have they used the EUMETSAT LSA-SAF product ?

In this study the downwelling shortwave fluxes were extracted from Land-SAF (http://www.meteo.pt/landsaf/) radiation product developed by Météo-France. The information was added in the text L205.

-    P. 1147, L. 7: "while the longwave was calculated": how, inputs?

The longwave fluxes are calculated using the interpolated data and the formulation from Brutsaert (1975) which uses only inputs of measured surface air temperature and moisture amount. The information was added in the text L207 - L208.

- P. 1147, L. 8: here, and several times in the text, "precipitations" (precipitation).

We agree with your comment. The correction was made in the text.

- P. 1147, L. 8: "were taken"?

We agree with your comment. The correction was made in the text.

We agree with your comment. A detailed analysis was performed and presented (see 4.1 – L235). Fig. 1 was replaced by Table 2 (page 19) where a statistical analysis between Caudete de las Fuentes1 (CA FU1) rain gauge and of its nine PERSIANN neighbours (PP) for 2006 and 2007 is presented. Also, Fig.3 (page 24) was added showing the coordinates of the data used (CA FU1 and PP) in the statistical analysis.
Fig. 2 from the old version of the manuscript was also replaced by a scatterplot which contains a statistical analysis for 2006 and 2007 (Fig. 5 - page 26).

The clarification was made in the text. The phrase was replaced by: "The soil moisture comparison outlined in Fig. 7 indicates a wide range of accuracies when comparing several soil moisture data obtained using different precipitation estimates. These differences depend on season, being marked especially at the end of the year, when, as in the case of the rainfall amounts, an important disagreement is observed." (L324 – L327).

In order to demonstrate the interest of using these satellite data, new analyses were performed within the new version of the manuscript.

Table 2 from the old manuscript version was replaced by Table 3 (page 20) in the new version. The RMSE units as well as the bias and the efficiency were added. Table 3 from the old manuscript version was erased. However, Fig. 8 (page 29) contains the RMSE, the correlation, the Mbias and the efficiency between the spatialized soil moisture databases obtained using in situ observations from VAS area and the PERSIANN satellite rainfall estimates for 2006 and 2007.

The AMSR-E frequencies are sensitive to the radiative emission of the surface but also to the vegetation layer. The algorithm to retrieve the soil moisture from AMSR-E brightness temperatures are then influenced by the vegetation. We have shown that the AMSR-E soil moisture follows the vegetation cycle.
Studies showed that the polarization ratio depends primarily on soil moisture, vegetation and atmosphere (Kerr and Njoku, 1990; Njoku et al., 2003; Owe et al., 2001). In our study we showed that the polarization ratio in C-band was in better agreement with simulated soil moisture than the AMSR-E soil moisture product.

Fig 5 is the same kind of figure as the one from Juglea et al. HESSD, 7, 649-686, 2010.
But, the spatialized PERSIANN soil moisture is added and also different years are considered.

Soil moisture modelling of a SMOS pixel : interest of using the PERSIANN database over the Valencia Anchor Station

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Abstract.

In the framework of Soil Moisture and Ocean Salinity (SMOS) Calibration/Validation activities, this study presents the interest of using the PERSIANN -CCS[1] database into hydrological applications with the goal of accurately simulating a whole SMOS pixel by representing the

5 spatial and temporal heterogeneity of the soil moisture fields over a wide area ($50 \times 50\,\mathrm{km}^2$). The study is focused over Valencia Anchor Station (VAS) experimental site, in Spain, which is one of the main test sites in Europe for the SMOS Calibration/Validation (Cal/Val) activities. At SMOS pixel scale ($50 \times 50\,\mathrm{km}^2$), having an accurate estimation of the amount and temporal/spatial distribution of precipitation is a critical issue so as to have a faithful representation

10 of the soil moisture distribution. To quantify the gain of using PERSIANN instead of distributing sparse rain gauge measurements, point-like and areal comparisons between in situ observations and satellite rainfall is done. An overestimation of the satellite rainfall amounts is observed in most of the cases but the precipitation patterns are in general retrieved.

To simulate the high variability in space and time of surface soil moisture, a Soil Vegetation

15 Atmosphere Transfer (SVAT) model - ISBA (Interactions between Soil Biosphere Atmosphere) is used. The interest of using satellite rainfall estimates as well as the influence that the precipitation events can induce on the modelling of the water content in the soil is depicted by a comparison between different soil moisture data. Point-like and spatialized simulated data using meteorological observations or PERSIANN - CCS database as well as ground measure-

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[1]Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Cloud Classification System – http://chrs.web.uci.edu/persiann

1

20 **ments are used. It is shown that a good consistency is reached in most part of the year, the**
precipitation differences having less impact upon the simulated soil moisture. The behaviour
of surface soil moisture at SMOS scale is verified by the use of remote sensing data from the
Advanced Microwave Scanning Radiometer on Earth observing System (AMSR-E). We show
that the PERSIANN database provides useful information at temporal and spatial scales in the
25 **context of soil moisture retrieval.**

1 Introduction

Numerous studies have shown that L-band radiometry is the most relevant remote sensing technique to monitor surface soil moisture over land surfaces and at global scale (Wang et al., 1990a; Schmugge et al., 1992; Jackson et al., 1995, 1999). In this framework, ESA's Soil Moisture and 30 Ocean Salinity (SMOS) mission has, as one of its main goals, to map global fields of surface soil moisture with an accuracy better than $0.04\,\text{m}^3\,\text{m}^{-3}$ and a temporal resolution of 2-3 days (Kerr et al., 2001). **The SMOS mission is based on a dual polarized L-band (1.4 GHz) radiometer using aperture synthesis (two-dimensional [2-D] interferometer) so as to achieve a maximum spatial resolution of 55 km over land (43 km on average over the field of view), providing multi-** 35 **angular dual polarized (or fully polarized) brightness temperatures over the globe (Kerr et al., 2001).**

The validation and calibration of the SMOS measurements is a crucial phase of the mission. In this context, a representative value of a whole SMOS pixel which can be compared to a satellite product at any overpass time is needed. To achieve this goal, it is essential to charac- 40 **terize and monitor an area slightly larger than the actual pixel (3dB footprint) in terms of soil moisture/brightness temperature. The Valencia Anchor Station (VAS) experimental site was selected as a key site providing in situ measurements over an area as wide as a SMOS pixel (Lopez-Baeza et al., 2005a; Delwart et al., 2007).**

Observing the spatial distribution of soil moisture at the catchment scale is a difficult task 45 **requiring dense sampling to achieve a good accuracy. Distributed soil moisture fields over the entire VAS area are obtained by the use of a Soil-Vegetation-Atmosphere-Transfer (SVAT) scheme called SURFEX (Externalized Surface) – module ISBA (Interactions between Soil-Biosphere-Atmosphere) (Noilhan and Planton, 1989; Noilhan and Mahfouf, 1996). The ability to reproduce the high temporal and spatial heterogeneity of soil moisture fields at SMOS pixel** 50 **scale using sparse in situ measurements over Valencia Anchor Station was investigated by Ju-glea et al. (2010).** At SMOS pixel scale ($50\times50\,\text{km}^2$) soil moisture variability is mostly driven by atmospheric forcing effects, thus mainly being influenced by climatic conditions at large scale and precipitation. The estimation of water content in the soil requires an understanding of the spatial and temporal variability of the rainfall. The potential of using high spatial resolution $0.04\times0.04°$

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55 PERSIANN-CCS (Precipitation Estimation from Remotely Sensed Information using Artificial Neu-
ral Networks-Cloud Classification System – http://chrs.web.uci.edu/persiann) satellite rainfall data
(Hong et al., 2004) in the framework of the SMOS Calibration/Validation (Cal/Val) activities is re-
ported in this paper. The advantage of using the PERSIANN-CCS database is to improve the soil
moisture modelling in situations where there are few or no rain-gauge data to allow reliable esti-
60 mates of spatial rainfall. Actually, the PERSIANN-CCS estimates are among the satellite rainfall
databases with the highest spatial ($0.04 \times 0.04°$) and temporal (1 hour) resolution.

Rainfall data availability has been highlighted as a major constraint on the effective application
of water resource models, and it has been argued that quality of rainfall inputs to the model is often
more important than the choice of the model itself (Wilk et al., 2006). Spatial rainfall estimates
65 derived from rain-gauges are widely used as input to hydrological models and as "ground truth"
for satellite rainfall measurements (Seed and Austin, 1990). The incorporation of satellite-based
rainfall estimates in hydrological modelling is expected to offer an alternative to ground based rain-
fall estimates. The use of satellite-based information to improve spatial rainfall estimates has been
widely reported (Hsu et al., 1999; Sorooshian et al., 2000; Grimes and Diop, 2003). However, few
70 studies have investigated so far the application of these data sets in hydrological models. Stud-
ies were conducted to evaluate the performance of hydrological models using operational satellite
rainfall estimates in southern Africa (Thorne et al., 2001; Hughes et al., 2006; Hughes, 2006; Wilk
et al., 2006). **Collischonn et al. (2008) evaluated the rainfall estimates of the Tropical Rainfall
Measuring Mission (TRMM) satellite over the Tapajos river basin in Amazon. Gottschalck
75 et al. (2005) studied the impact of different precipitation products on soil state and Ming et al.
(2010) forced a Land Surface Model with both satellite estimates and in-situ measurements to
test how well they can predict hydrologic states and fluxes useful for water resource applica-
tions. Both studies were carried out over the continental United State region. In this paper, we
force a SVAT scheme with both satellite and ground reference data over the Valencia Anchor
80 Station (VAS) area. Firstly, an evaluation of the skill of the PERSIANN products to replicate
the variability of gauge rainfall amounts and occurrence at point and areal scale is performed.
Then, the capacity of PERSIANN satellite rainfalls to be used as input to a hydrological model
is tested. ISBA is used to simulate the spatial and temporal heterogeneity of the soil moisture
fields at point and spatialized scale. Comparisons between simulated soil moisture and ground
85 measurements are performed.**

**Satellite remote sensing approaches open the possibility to provide spatially integrated in-
formation on soil moisture over large areas. Several papers investigated these soil moisture
remote sensing products (Wagner et al., 2007; Rüdiger et al., 2009; Gruhier et al., 2010). In
this framework, the spatialized soil moisture product obtained using PERSIANN rainfall data
90 is tested by comparing with the spatialized soil moisture obtained using in situ rain gauges as
well as with remote sensing products derived from AMSR-E (Advanced Microwave Scanning**

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Radiometer of the Earth Observing System).

2   Studied area and data

2.1   Valencia Anchor Station

95 **The Valencia Anchor Station site is located in the South East of Spain, about 80 km inland to the West of Valencia. It was selected by ESA with the main objective to characterize a large-scale reference area. It is dedicated specifically to the validation and calibration of low spatial resolution Earth Observation data and products. The site, defined within the natural region of the Utiel-Requena Plateau, represents a reasonably homogeneous area of about $50 \times 50\,\text{km}^2$**

100 **(Lopez-Baeza et al., 2008), mainly dedicated to vineyard crops (about 75% cover), and other Mediterranean land uses (shrubs, oaks, pine, olive and almond trees, etc). From a microwave point of view, the area remains as a ploughed bare soil for about half a year.**

VAS is a semiarid environment with low annual precipitation (around 400 mm) and is characterized by an extensive set of measurements at different levels (both in the atmosphere and in the soil) in

105 order to derive surface energy fluxes. Over the VAS area ($50 \times 50\,\text{km}^2$) 22 meteorological stations, 4 fully equipped and 18 rain gauges, are randomly and not uniformly distributed (Fig. 1). **The 4 fully equipped stations provide meteorological data: air temperature and humidity at screen level, atmospheric pressure, precipitation, wind speed and direction and solar and atmospheric radiation.**

110 **Over the $50 \times 50\,\text{km}^2$ area in situ soil moisture measurements are available. In this study, soil moisture data recorded during a campaign called Melbex 2 ($39.526°$N, $1.288°$W - Mediterranean Ecosystem L-Band characterization Experiment 2) are used. The campaign was carried out from April 2007 to December 2007 to observe the surface emission of vineyards (Cano et al., 2008). The soil is characterized as sandy clay loam, with a texture composed of 45%**

115 **sand and 26% clay. The soil moisture measurements were carried out every 10 min using capacitive probes. In the area, the soil was ploughed at least 3 times during the growing period of vineyards.**

Surface static fields (vegetation fraction, roughness, leaf area index (LAI), soil texture, and others) are accessible. A detailed description of the vegetation characteristics is available at 1 km

120 resolution based on ECOCLIMAP, a surface parameter database derived from land cover and climatic maps (Masson et al., 2003). **The LAI data comes from the MODIS instrument (Moderate Resolution Imaging Spectroradiometer; http://modis.gsfc.nasa.gov/) at 1 km spatial resolution provided on a daily and 8-day basis.** An accurate map representing the spatial distribution of clay and sand (Millan-Scheiding et al., 2008) at 10 m resolution covering all the $50 \times 50\,\text{km}^2$ area is

125 available.

4

2.2 PERSIANN database

The PERSIANN system for rainfall estimation is under development at The Center for Hydrometeorology and Remote Sensing at The University of California, Irvine. The fundamental algorithm is based on a neural network and can therefore be easily adapted to incorporate relevant information as it becomes available. The original system (Hsu et al., 1997) was based on geostationary infrared imagery and later extended (Hsu et al., 1999) to include the use of both infrared and daytime visible imagery. Further development of PERSIANN has included cloud image segmentation and classification for rainfall estimation at $0.04 \times 0.04°$ resolution (Hong et al., 2004). Instead of extracting local texture information in PERSIANN (Hsu et al., 1997, 1999; Sorooshian et al., 2000), PERSIANN-CCS extracts information from the whole cloud patch and provides multiple infrared brightness temperature versus rainfall rate (Tb-R) relationships for different cloud classification types.

The product used in this study is PERSIANN - CCS, hereafter referenced as PERSIANN. It is at $0.04 \times 0.04°$ spatial resolution in an hourly basis. It covers 60° S to 60° N globally and over the VAS area 221 PERSIANN points are distributed (see Fig. 1).

2.3 AMSR-E data

The Advanced Microwave Scanning Radiometer (AMSR) of the Earth Observing System (EOS) is a passive microwave scanning radiometer, operating at six wavelengths with an incidence angle of $55°$ (6.925, 10.65, 18.7, 23.8, 36.5, and 89 GHz) in horizontal and vertical polarizations. Launched on the Aqua satellite in May 2002, it operates in polar sun-synchronous orbit with equator crossing at 1:30 p.m. and 1:30 a.m. local solar time. Global coverage is achieved every two days or less depending on the latitude. The mean spatial resolution at 6.9 GHz is about 56 km. The data used in this study are AMSR-E Level 3 soil moisture and brightness temperature at 6.9 GHz (Njoku, 2004), and were provided by the National Snow and Ice Data Center (NSIDC). The inversion algorithm for the AMSR-E soil moisture uses the 10.7 GHz and 18.7 GHz brightness temperature data (Njoku et al., 2003). Using the brightness temperature at 6.9 GHz in horizontal (h) and vertical (v) polarizations, we computed the polarization ratio using:

$$\mathrm{PR} = \frac{Tb_v - Tb_h}{Tb_v + Tb_h} \tag{1}$$

It normalizes out the surface temperature and leaves a quantity that depends primarily on soil moisture, vegetation and atmosphere (Kerr and Njoku, 1990; Njoku et al., 2003; Owe et al., 2001). The AMSR-E brightness temperature and soil moisture products are re-sampled to a global cylindrical 25km Equal-Area Scalable Earth Grid (EASE-Grid) cell spacing (Njoku, 2004). Two AMSR-E pixels are covering the VAS area. The average of these two pixels is considered to be representative for the 50×50 km^2 area.

3   Methodology – ISBA modelling

160   **The model used to generate the temporal behaviour of the soil moisture from atmospheric forcing and initial conditions is called SURFEX (stands for surface externalisée – Le Moigne et al., 2009) and was developed at the National Center for Meteorological Research (CNRM) at Météo-France. It gathers all the developments and improvements made in surface schemes, containing four different modules: ISBA (Interactions between Soil-Biosphere-Atmosphere),**
165   **Sea and ocean, TEB (Town Energy Balance) and Lake. In this article only the module for the soil and vegetation - ISBA (Interactions between Soil-Biosphere-Atmosphere) (Noilhan and Planton, 1989; Noilhan and Mahfouf, 1996) is used.** ISBA simulates the interaction between the low-level atmosphere, the vegetation and the soil, by using a physically based method that solves the water and energy budgets of the soil-vegetation system. In this study, the modelling of the heat
170   and water transfers into the soil is based on the diffusive scheme – ISBA-DIF (Boone, 2000; Boone et al., 2000). More details about the choice of the parametrization can be found in Juglea et al. (2010). **The atmospheric forcing, needed to run the ISBA model, is composed of: air temperature and humidity at screen level, atmospheric pressure, precipitation, wind speed and direction and solar and atmospheric radiation.**

175   The soil moisture modelling is done in two steps: one consisted in a point modelling, followed by a spatialized one. The data processed is either in situ data from VAS area either remote sensed data from PERSIANN.

  – Point procedure

The point procedure consists into forcing the ISBA model in different points by using in
180   **situ meteorological observations and PERSIANN points. Data from two rain gauges called Caudete de las Fuentes (CA FU – 1.31° W, 39.52° N) and Caudete de las Fuentes 1 (CA FU1 – 1.27° W, 39.55° N) are used for this study. The nearest PERSIANN points used for this local study is the point PP149 (1.26° W, 39.54° N).** A common set of characteristics of the surface and atmospheric forcing are used for the three simulations (CA FU/CA FU1/PP149). However, as the
185   goal of this approach is to evaluate the influence of the precipitation patterns and amounts over the simulated soil moisture, rainfall data are considered different for each study case. **Analysis of the obtained soil moisture as well as comparisons with ground measurements are presented in the paragraph 4.2.1**.

  – Spatialized procedure

190   **In order to reproduce the high temporal and spatial heterogeneity of soil moisture fields over the entire VAS area, the $50 \times 50 \, \text{km}^2$ is divided into 25 areas of $10 \times 10 \, \text{km}^2$ each. Fig. 1 presents the spatial distribution of the available meteorological stations/rain gauges over the**

VAS $50 \times 50 \, \text{km}^2$ area. As an irregular distribution of the stations can be noticed (for example in the center of the area there is no data) an interpolation (Inverse Distance Weighted – IDW) using all the available meteorological stations is performed over the $10 \times 10 \, \text{km}^2$ grid as described in Juglea et al., 2010. To achieve an homogeneous sampling of the soil moisture over the entire area and so a spatialized soil moisture comparable with SMOS data, the SVAT model is driven at an hourly basis by interpolated atmospheric forcings and land surface data from VAS. Spatially distributed fields and forcing enable to simulate soil moisture spatial and temporal behaviour. Once the soil moisture fields are known over the $50 \times 50 \, \text{km}^2$ grid, it is possible to compare to satellite products. Spatialized soil moisture values outputted from SVAT are averaged to produce a mean value of soil moisture representative over the $50 \times 50 \, \text{km}^2$ area (VAS).

The VAS area covers 221 PERSIANN points. The temperature, atmospheric pressure, wind speed, wind direction and the relative humidity are interpolated (IDW) over the $4 \times 4 \, \text{km}^2$ grid using the 4 complete meteorological stations. The downwelling shortwave fluxes are extracted over the same grid from the Land-SAF (http://www.meteo.pt/landsaf/) radiation product while the longwave fluxes are calculated using the interpolated data and the formulation from Brutsaert (1975) which uses only inputs of measured surface air temperature and moisture amount. The roughness and the fraction of vegetation (ECOCLIMAP) and the LAI (MODIS), are at 1 km resolution. Due to their different spatial resolutions when compared to the $4 \times 4 \, \text{km}^2$ grid, these products are aggregated through a spatial mean. Texture maps (sand and clay) are available at 10m resolution. In this case, the aggregation to the $4 \times 4 \, \text{km}^2$ is done by considering the main class of texture into the grid cell. In order to evaluate the PERSIANN database, the SVAT model is also driven by the 221 satellite rainfall estimates and the data from the VAS area. All the PERSIANN points covering the VAS site lead to 221 soil moisture points, from which the average is computed.

To check the behaviour of both spatialized soil moisture data (using in situ observations – VAS or satellite estimates – PERSIANN), a comparison with existing products derived from AMSR-E is performed. In the paragraph 4.2.2, equivalences between the simulated soil moisture using different input data as well as comparisons of spatialized soil moisture and remote sensing products from AMSR-E are discussed. .

4   Results

In order to test the ability of the PERSIANN satellite rainfalls to be used as an input of a hydrological model so as to accurately simulate a whole SMOS pixel, an evaluation of the product is undertaken. Firstly, rain rates comparisons at point/areal scale between in situ observations and the PERSIANN points is done. Secondly, ISBA is used to simulate the spatial and temporal heterogeneity of the soil moisture fields at point and spatialized scale. Comparisons between

simulated soil moisture and ground measurements as well as comparisons between spatialized soil moisture data using meteorological observations from VAS/ PERSIANN database are de-

230   **picted next. To test which spatialized soil moisture (VAS or PERSIANN) behaviour is best, a two year comparison with AMSR-E data products is performed. The soil moisture simulations are extracted for the time steps close to the overpass times of the satellites. As AMSR-E penetration depth is of about 2 cm, the simulated soil moisture integrated over the first 2 cm is considered. The results are detailed in the next section.**

235   4.1   Rainfall comparison

In this section, the skill of the PERSIANN products to replicate the gauged variability of rainfall amounts and occurrence is investigated for 2006 and 2007. **Fig. 2 presents monthly comparisons between all the meteorological stations within the 50×50 km^2 VAS area and their nearest PERSIANN points (PP) for 2007. Although there is a general agreement in rainfall patterns, the**

240   **precipitation values produced by PERSIANN substantially overestimate the rainfall amounts in comparison with the gauges. If from March to August comparable rainfall amounts and variability are observed, in winter PERSIANN overestimates the amount of rainfall. This overestimation is more noticeable during 2006 (not showed), when the rain gauges records an amount of rainfall smaller than 50 mm/month in September whereas the PERSIANN products**

245   **systematically exceeds 150 mm/month. For 2007, the same important differences are observed for the month of January and February. Table 1 summarizes the results for the entire VAS catchment and lists both the root-mean square error (RMSE) and the mean bias (Mbias) of daily precipitation between each in situ rainfall observation and PERSIANN points. It shows that the PERSIANN product indicates in most of the considered cases equivalent spatial and**

250   **temporal error over the VAS area. As PERSIANN data seriously overestimate the rainfall a further calibration and adjustment of the satellite data using in situ observations can be suggested.**

In order to encounter the spatial variability of the PERSIANN product, a representative rain gauge called Caudete de las Fuentes 1 (CA FU1) is analysed more in depth. The coordinates of this

255   rain gauge are depicted in Fig. 3, where all the PERSIANN (PP) neighbours points chosen for the comparison are also presented. The precipitation events occurring during the years 2006 and 2007 at the CA FU1 rain gauge and at the nearest PERSIANN points are analysed and Table 2 summarizes the differences in terms of RMSE and Mbias. **In this case also, substantial differences between the different rainfall data in terms of range and temporal variability are observed.** PERSIANN

260   overestimates rainfall in general compared to the gauges, especially in the rainy seasons, which was also found over India by Brown (2006) and across Australia, the Pacific, parts of Asia by Sorooshian et al. (2000). The more significant difference is observed in September 2006, when the amount of rainfall between the PERSIANN points and CA FU1 rain gauge is considerably different. If

the CA FU1 rain gauge records a slight amount of rainfall, all the PERSIANN points (PP) shows

265 rainy events going beyond 20 mm/day. During the summer season, the rain gauge as well as the
PERSIANN products compare well. During the months of June, July and August (2006, 2007) the
amount of rainfall is comparable for both cases. Among this period the CA FU1 rain gauge records
rainfall amounts at around 45 mm while the PERSIANN points shows rainfall amounts of about 70
mm.

270   The fact that the satellite data represent areal rainfall, while the gauge data represent point rainfall
can also induce precipitation differences. **In this context, an interpolated (IDW) rainfall product
obtained using all the available in situ observation over VAS is used. This product is representative over a $10 \times 10 \, \text{km}^2$ area. Fig. 4 presents the location as well as the differences when
comparing the interpolated rainfall ($10 \times 10 \, \text{km}^2$) with the spatial mean of the 12 PERSIANN**

275 **points available within the same grid. To encounter the spatial resolution differences, a comparison of the interpolated rainfall and each PERSIANN point available within the $10 \times 10 \, \text{km}^2$
grid is performed. The analysis is done for 2007 at a daily scale. A slight improvement in terms
of RMSE and R^2 is obtained when comparing data at the same spatial resolution. For instance,
when comparing the interpolated rainfall with each nearest PP no correlation is observed and**

280 **the RMSE value is above 6.73 mm/day in most cases. In the case of comparing the satellite
based estimates spatially averaged and the interpolated precipitation, R^2 = 0.23 -/- and the
RMSE is about 5.32 mm/day. This results highlight the importance of comparing equivalent
spatial products, meaning that the scaling issue has to be considered.** It should be noted also the
fact that the PERSIANN system involves no local calibration in producing its rainfall estimates. This

285 means that the PERSIANN product can be improved by taking into account the characteristics of the
considered region. However, downscaling of remotely sensed data remains an issue and hence these
satellite-based rainfall estimates do not compare very well with the gauge data/interpolated data, a
low correlation being obtained. This can also be due to the important variability of the precipitation
occurrence over the VAS area. This variability can be seen by comparing at a daily scale the chosen

290 rain gauge CA FU1 with other in situ rain gauge situated at about 4 km (Caudete de las Fuentes –
CA FU) - see Fig. 3 to localize both rain gauges. Despite their proximity, the recorded rainfall at
the two stations for 2006 is not highly correlated (R^2 = 0.36 -/-) neither (see Fig. 5).

4.2   Soil moisture

4.2.1   Point to point comparison between soil moisture data

295 The objective of this comparison is to assess whether the satellite data can be used instead of gauge
data as inputs to a hydrological model. Precipitation is considered as an important factor in controlling spatial and temporal patterns of soil moisture, especially in arid and semiarid regions (Grayson
et al., 2006). In this context, the SVAT model is driven using different precipitation database: from

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the CA FU and CA FU1 rain gauges and also from the PERSIANN point PP149. **The in situ soil**
300 **moisture considered was recorded during Melbex 2 campaign, from April 2007 to December**
2007.

In order to observe the difference that the precipitation events can induce on the modelling of
soil moisture, Fig. 6 illustrates a comparison at an hourly scale between the three simulated
soil moisture data (CA FU, CA FU1 and PP149) and ground measurements. The considered
305 **period is from June to December 2007 and the soil moisture is representative over 5 cm depth.**
The SVAT simulations indicate that there is a considerable impact on land surface states when
using different precipitation forcing. The simulations using CA FU, CA FU1 or PP149, all
show some differences from the observed soil moisture. The RMSE values are ranging from
$0.02\,\mathrm{m^3\,m^{-3}}$ for CA FU1, $0.05\,\mathrm{m^3\,m^{-3}}$ for PP149 and $0.06\,\mathrm{m^3\,m^{-3}}$ for CA FU. The pattern of
310 **differences, however, varies considerably. For instance, the CA FU simulation depicts dryer**
soil moisture values within the considered period. The precipitation total amount recorded
along the considered period is of 189.85 mm. The CA FU recorded rainfall amount is compa-
rable with the amount of rainfall recorded at CA FU1 rain gauge of 172.08 mm. However, the
precipitation occurrence registered from CA FU is more widely distributed in time, causing a
315 **longer period of dry soil moisture values. The PP149 runs indicate generally a much wetter**
soil than the measured one. This pattern is consistent with the overestimation of late fall and
winter precipitation by the satellite products. A total rainfall amount of 324.08 mm within the
considered period is encountered, almost twice than the total rain gauges amount. The CA
FU1 simulation, on the other hand, illustrates substantially less error from the observed soil
320 **moisture.**

A more detailed analysis over a longer period is performed using the simulated soil moisture data.
Fig. 7 compares the soil moisture data simulated at 5 cm depth at an hourly resolution for 2006 and
2007. The statistical analysis of the comparison between the three configurations is summarized in
Table 4. **The soil moisture comparison outlined in Fig. 7 indicates a wide range of accuracies**
325 **when comparing several soil moisture data obtained using different precipitation estimates.**
These differences depend on season, being marked especially at the end of the year, when, as in
the case of the rainfall amounts, an important disagreement is observed. For 2006, when comparing
the soil moisture using the CA FU1 rain gauge and the PP149 an RMSE value of $0.07\,\mathrm{m^3\,m^{-3}}$
(RMSE = $0.06\,\mathrm{m^3\,m^{-3}}$ between soil moisture CA FU rain gauge/ PP149) is obtained. If only the
330 period from January to the end of August 2006 is considered a noticeable improvement of the results
is observed. An RMSE of $0.03\,\mathrm{m^3\,m^{-3}}$ is found between CA FU1/ PP149 (respectively $0.03\,\mathrm{m^3\,m^{-3}}$
– CA FU/ PP149). The correlation values are also better, reaching values of 0.76 -/- (instead of 0.55
-/-) for the first case (CA FU/ PP149) and 0.70 -/- (instead of 0.51 -/-) for the second case (CA FU1/
PP149). **The greatest differences are generally observed during the late fall and winter season**.
335 To understand these differences obtained at the end of the year, a more detailed analysis is done for

September (days of the year from 244 to 273). If the PP149 is considered, a monthly precipitation average of 5.20 mm/day results into a monthly mean of soil moisture of 0.19 m^3 m^{-3}. In the case of CA FU1 rain gauge, a monthly precipitation average of 0.89 mm/day results into a monthly mean of soil moisture of 0.12 m^3 m^{-3}. **The same difference is obtained also in the case of using CA FU rain gauge. From September to December, an RMSE of 0.09 m^3 m^{-3} is found between CA FU1/ PP149 (respectively 0.11 m^3 m^{-3} – CA FU/ PP149) and the correlation values of 0.49 -/- for CA FU1/ PP149 and 0.42 -/- for CA FU/ PP149. For 2007, the simulated soil moisture using PP149 is slightly higher than the other soil moisture data, causing a little degradation of the scores. However, at the end the year, from September to December, the impact of the precipitation is less significant than for 2006, an RMSE of 0.06 m^3 m^{-3} is found between CA FU1/ PP149 (respectively 0.10 m^3 m^{-3} – CA FU/ PP149). The correlation values are also better, attending values of 0.55 -/- for CA FU1/ PP149 and 0.45 -/- for CA FU/ PP149.**

In the previous section, when comparing the rain gauges against the satellite estimates, we obtain also some discrepancies. We conclude that one of the factors that can cause these discrepancies can be due to the fact that the satellite data represent areal rainfall, while the gauge data represent point rainfall. In the following section the comparison is done between equivalent products, both representative over the VAS area – 50×50 km^2.

4.2.2 Spatialized soil moisture over VAS area

Two spatialized soil moisture data are compared: one spatialized soil moisture obtained using the gauge data combined through an areal interpolation approach (IDW) and another spatialized soil moisture data obtained using the satellite rainfall estimates. The comparison between both data is made for 2006 and 2007. Fig. 8 compares the two spatialized soil moisture data: VAS and PER-SIANN at 5 cm depth. **In order to better understand the seasonal variations of the impact of the PERSIANN precipitation products on the simulated soil moisture, we focused on a monthly analysis.** In the first part of the year both amplitude and variation of the soil moisture are retrieved. For 2006, from the beginning of the year until May, an RMSE value equal to 0.03 m^3 m^{-3} is found and a correlation coefficient of 0.74 -/-. The good statistics results are also obtained from first of June until the end of August when the RMSE value is very low 0.01 m^3 m^{-3} and the R^2 = 0.60 -/-. During all this period, from the beginning of the year to the end of the summer, a good agreement between both data is observed (RMSE = 0.03 m^3 m^{-3} and R^2 = 0.83 -/-). Although the simulated soil moisture using satellite estimates generally perform well, there are some exceptions, however. At the end of the year (from September), when the precipitation amount is the most different, the RMSE value is higher than the rest of the year (RMSE = 0.08 m^3 m^{-3}) and the correlation coefficient is lower compared to the other periods R^2 = 0.56 -/-. For 2007 the spatialized soil moisture statistics are within the same range as for 2006. At the beginning of the year, from January to the end of May the RMSE = 0.06 m^3 m^{-3} (R^2 = 0.68 -/-), from June to the end of August the RMSE

= 0.04 m^3 m^{-3} (R^2 = 0.82 -/-) and at the end of the year, from September to December the RMSE = 0.06 m^3 m^{-3} (R^2 = 0.65 -/-). The precipitation differences at the end of the year 2007 are less significant, inducing less errors in the simulated soil moisture.

375 Point to point comparison between soil moisture data are influenced by the rainfall events and occurrence differences. The use of spatialized data (average of several simulated grid points) attenuate these influences, leading to more consistent soil moisture results.

4.2.3 Comparison with AMSR-E data

Two soil moisture data basis representative over the Valencia Anchor Station (50×50 km^2 area)

380 are considered (VAS and PERSIANN) and tested by a comparison with remotely sensed data from AMSR-E. Soil moisture (Njoku L3) and the polarization ratio at 6.7 GHz products are considered. The increased attenuation by vegetation and the superficial sensing depth for higher frequencies is a limit in the soil moisture retrieval from AMSR-E data. As the vegetation has an important influence on the measured signal at these frequencies, the polarization ratio is used. It provides a

385 better agreement (than the soil moisture product from AMSR-E) with simulated soil moisture even in the vegetation growing period (Juglea et al., 2010). The penetration depth of AMSR-E sensor is considered to be of about 2 cm so the simulated soil moisture representative over 2 cm depth is considered. **As the AMSR-E soil moisture product shows biases and very small amplitude (Rüdiger et al., 2009; Gruhier et al., 2010), a normalization between [0, 1] is done for all the soil**

390 **moisture data within this paragraph. The normalized AMSR-E soil moisture data display a very high variation. The comparison was done for 2006 and 2007.** Fig. 9 compares the three soil moisture products and the Table 4 summarizes the differences encountered within the considered product. All statistics presented in the following sections are calculated for the normalized soil moisture values and are, therefore, dimensionless. In general we can observe that the dynamics of the

395 soil moisture are well captured during the whole year. During the first part of the year, the AMSR-E product and modelled spatialized soil moisture estimate levels are comparable. **In the middle of the year, as the AMSR-E signal is perturbed by the vegetation, the comparison is done with the polarization ratio. The AMSR-E soil moisture product shows only low correlations with any of the VAS or PERSIANN datasets. The spatialized soil moisture is found to be in**

400 **better agreement with the polarization ratio which shows a good representation of the dynamic behaviour of the soil moisture content. A good correlation exists between the three datasets (VAS, PERSIANN and AMSR-E polarization ratio), with a range of the correlation coefficient from 0.40 -/- to 0.67 -/- for both 2006 and 2007. During the spring and summer season for 2006 and 2007 the three products compare well. The higher agreement during this period**

405 **is important because it shows that although the PERSIANN products overestimate the total rainfall during the year, during this period precipitation are accurately represented by this satellite estimates. Although there is a general agreement in soil moisture patterns, the high**

precipitation satellite estimates during the late fall and winter induce an overestimation of PERSIANN soil moisture compared with AMSR-E products and VAS data. For this period, the spatialized VAS data is more in agreement with the AMSR-E products than the spatialized PERSIANN data.

5   Conclusions

In the framework of Calibration and Validation activities of the Soil Moisture and Ocean Salinity mission, obtaining a brightness temperature comparable with the instrument measurements is an important issue. A good knowledge of soil moisture over a large area is then necessary. Precipitation amounts and occurrence are considered as an important factor in controlling spatial and temporal patterns of the soil moisture. Due to its high variability in space and time as well as its highly intermittent occurrence, measuring precipitation requires dense sampling to achieve a good accuracy. The study is performed over the Valencia Anchor Station (2006–2007) which provides in situ data at large scale. Meanwhile, the sparse distribution of the gauges within the area can be a limit to our approach. In this context, this paper investigates the ability of PERSIANN rainfall estimates to give access to a higher spatial and temporal distribution of the precipitation.

An evaluation of PERSIANN rainfall amount and occurrence was undertaken. Local meteorological station/gauge data and the PERSIANN estimates do not compare very well. During the summer season, when the precipitation occurrence and amounts are less important, patterns in rainfall are better reproduced. However, during late fall and winter substantial differences between the different rainfall data in terms of range and temporal variability are observed. This can be explained by the variability of the rainfall over the VAS region and also by the scale difference of the databases. Whereas rain gauges record the rainfall at a point, the PERSIANN satellite estimates integrate the amount of rain over a wider area. Although important local differences exist, averages at equivalent scale show results in better agreement.

Used as input to a SVAT model – ISBA – the PERSIANN product has an important impact when it is used in local modelling. However, the differences in soil moisture are much lesser than the differences in precipitation forcing. Nevertheless, there are periods (late fall and winter) when the soil moisture differences are of equivalent magnitude to that of the precipitation forcing. A wide range of accuracies when comparing several soil moisture data obtained using different precipitation estimates is observed. These differences depend on the season, being marked especially at the end of the year, when, as in the case of the rainfall, an important disagreement is observed.

Two spatialized soil moisture information representative over the $50 \times 50 \, \text{km}^2$ are obtained using ISBA coupled to a set of forcings and a good knowledge of soil types and land use. One

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**spatialized soil moisture is obtained using the gauge data combined through an areal interpo-
lation approach (IDW) and another spatialized soil moisture data obtained using PERSIANN
satellite rainfall estimates. The simulated soil moisture using satellite estimates generally per-
forms well, both amplitude and variation being retrieved. However, at the end of the year
(from September), when the precipitation amounts are the most different, the RMSE value is
higher than the rest of the year. This spatialized approach significantly improves the results.
To check the validity of both spatialized soil moisture data, a comparison with AMSR-E prod-
uct is performed. Although AMSR-E surface soil moisture product is not able to capture the
absolute value, it provides reliable information on surface soil moisture temporal variability,
at seasonal and rainy events scale. In general we can observe that the dynamics of the soil
moisture are well captured during the whole year by both spatialized soil moisture databases
(VAS and PERSIANN). From April to September, during the vegetation growing season the
AMSR-E signal is very perturbed inducing an important error in the soil moisture product.
The use of the polarization ratio at 6.9 GHz provides a better agreement with simulated soil
moisture. The spatialized soil moisture obtained using the VAS in situ observation is, in gen-
eral, more in accordance with the AMSR-E products than the spatialized soil moisture data
obtained using PERSIANN satellite estimates.**

**The rainfall differences reported above are sometimes consequent and can produce consid-
erable impacts on seasonal weather and climate forecasts when used for land surface model
initialization. This indicates the importance of using the most accurate precipitation database,
as large differences are in most of the cases directly translated into equally high errors in soil
moisture. The satellite derived rainfall estimates seem to have potential to contribute to ex-
tending model simulations and water resource estimations into the future. Further work will
imply simulation of the SMOS brightness temperature using the simulated soil moisture ob-
tained from the presented work. Comparison with SMOS data will give us more information
about which precipitation database to be considered in our approach.**

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Table 1. List of all the meteorological stations/ rain gauges (1st column) and their nearest PERSIANN points (2nd column) available over the VAS area. The root-mean square error (RMSE) and the mean bias (Mbias) of daily precipitation between each in situ rainfall observations and PERSIANN points are calculated for 2006 and 2007.

Station Name	PERSIANN point	2006 RMSE mm/day	Mbias mm/day	2007 RMSE mm/day	Mbias mm/day
CASAS DE VES	28	5.69	0.80	6.04	0.90
CASAS IBANEZ	42	6.96	0.90	6.95	1.11
VILLAMALEA	56	6.13	0.77	6.57	1.02
REQUENA LA PORTERA COOP.	102	6.04	0.82	6.43	1.11
REQUENA CAMPO ARCIS	100	4.79	0.77	5.82	1.06
DEL MORO CHJ	130	5.82	0.76	5.92	0.94
REQUENA	136	5.31	0.81	6.31	1.19
CAUDETE DE LAS FUENTES	148	5.58	0.73	5.95	1.03
MINGLANILLA	141	5.70	0.34	5.98	0.79
PRESA DE CONTRERAS	143	6.15	1.08	6.72	0.76
UTIEL CHJ	167	5.83	0.76	6.92	1.59
UTIEL	167	6.03	0.69	6.93	1.55
UTIEL (LA CUBERA)	166	5.61	0.71	6.38	1.69
CAMPORROBLES COOPERATIVA	196	5.86	0.75	5.53	0.70
CAMPO ARCIS	100	4.75	0.77	5.22	1.00
CERRITO REQUENA	119	5.55	0.78	5.53	1.08
VAS	165	5.71	0.91	5.26	1.02
GRAJA DE INIESTA	122	4.54	0.62	5.43	0.80
CONTRERAS	143	6.03	0.86	6.53	0.82
CAUDETE DE LAS FUENTES 1	149	5.52	0.68	5.93	1.23
VILLAMALEA 1	72	4.80	0.75	6.20	1.01
CERRO	24	4.87	0.76	5.48	1.01

Table 2. Daily statistical analysis between Caudete de las Fuentes1 (CA FU1) rain gauge and of its nine PERSIANN neighbours (PP) for 2006 and 2007.

Rain gauge CA FU1/PERSIANN point	2006		2007	
	RMSE	Mbias	RMSE	Mbias
	mm/day	mm/day	mm/day	mm/day
CA FU1/PP131	5.64	0.71	5.19	1.02
CA FU1/PP132	5.44	0.69	5.70	1.06
CA FU1/PP133	5.79	0.84	5.79	1.25
CA FU1/PP148	5.60	0.69	5.36	1.04
CA FU1/PP149	5.53	0.68	5.93	1.24
CA FU1/PP150	5.61	0.74	6.35	1.45
CA FU1/PP165	5.66	0.71	5.31	1.09
CA FU1/PP166	5.62	0.74	6.12	1.35
CA FU1/PP167	5.64	0.79	6.42	1.61

Table 3. Statistical analysis between simulated local soil moisture at 5 cm depth using Caudete de las Fuentes (CA FU), Caudete de las Fuentes1 (CA FU1) and the PERSIANN point PP149. The study is performed for 2006 and 2007.

		CA FU/PP149	CA FU1/ PP149	CA FU1/CA FU
2006	RMSE $m^3 m^{-3}$	0.07	0.06	0.03
	R^2 -/-	0.55	0.50	0.87
	Mbias $m^3 m^{-3}$	0.04	0.02	-0.02
	Eff -/-	-0.75	0.08	0.74
2007	RMSE $m^3 m^{-3}$	0.09	0.06	0.05
	R^2 -/-	0.54	0.61	0.81
	Mbias $m^3 m^{-3}$	0.07	0.04	-0.04
	Eff -/-	-2.23	0.23	0.50

Table 4. Statistical analysis between SM VAS (spatialized soil moisture obtained using in situ observations), SM PERSIANN (spatialized soil moisture data obtained using PERSIANN satellite rainfall estimates), SM AMSR-E (AMSR-E soil moisture product) and PR AMSR-E (AMSR-E polarization ratio 6.9 GHz). The comparison is made for 2006 and 2007.

		RMSE -/-	R^2 -/-
2006	SM VAS/SM AMSR-E	0.24	0.07
	SM PERSIANN/SM AMSR-E	0.26	0.01
	SM VAS/PR AMSR-E 6.9 GHz	0.17	0.50
	SM PERSIANN/PR AMSR-E 6.9 GHz	0.17	0.41
2007	SM VAS/SM AMSR-E	0.19	0.38
	SM PERSIANN/SM AMSR-E	0.20	0.24
	SM VAS/PR AMSR-E 6.9 GHz	0.13	0.67
	SM PERSIANN/PR AMSR-E 6.9 GHz	0.14	0.53
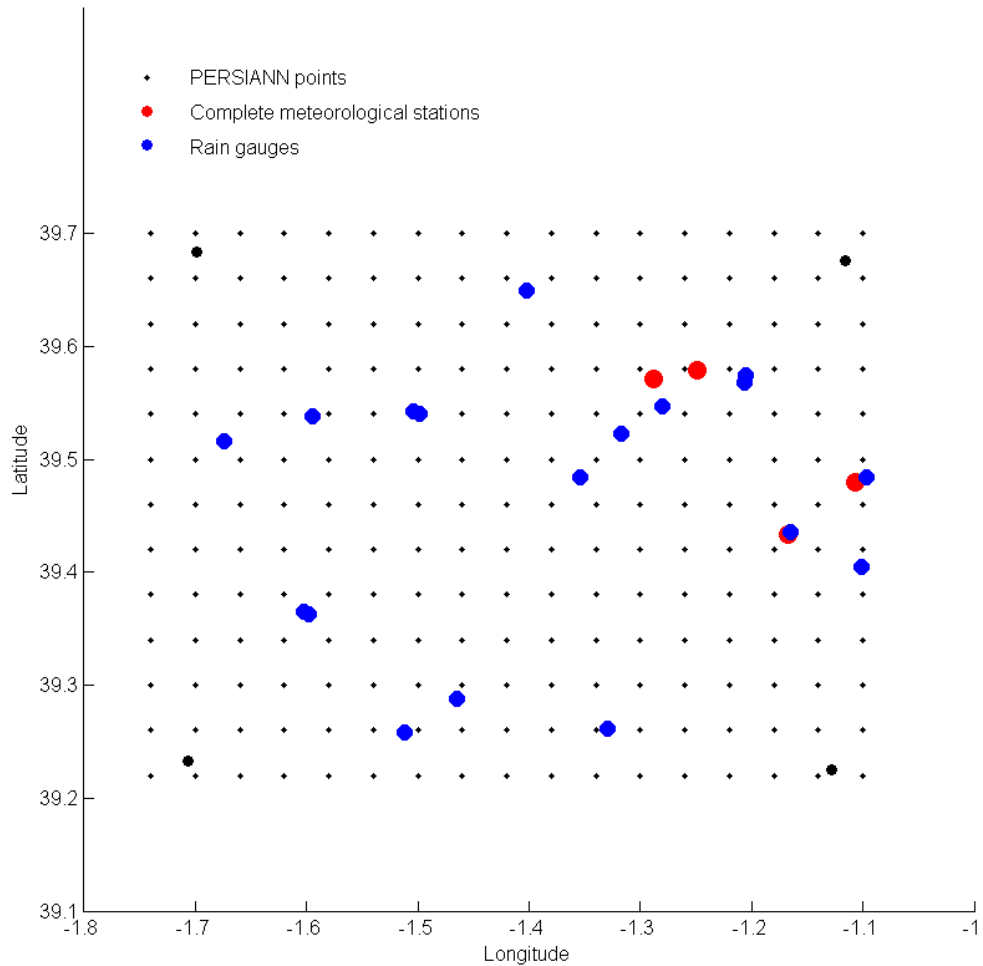
Fig. 1. Distribution of the in situ meteorological stations (red dots) and rain gauges (blue dots) over the $50 \times 50\,\text{km}^2$ VAS area (the four large black dots representing its limits). The PERSIANN points are represented in small black dots.
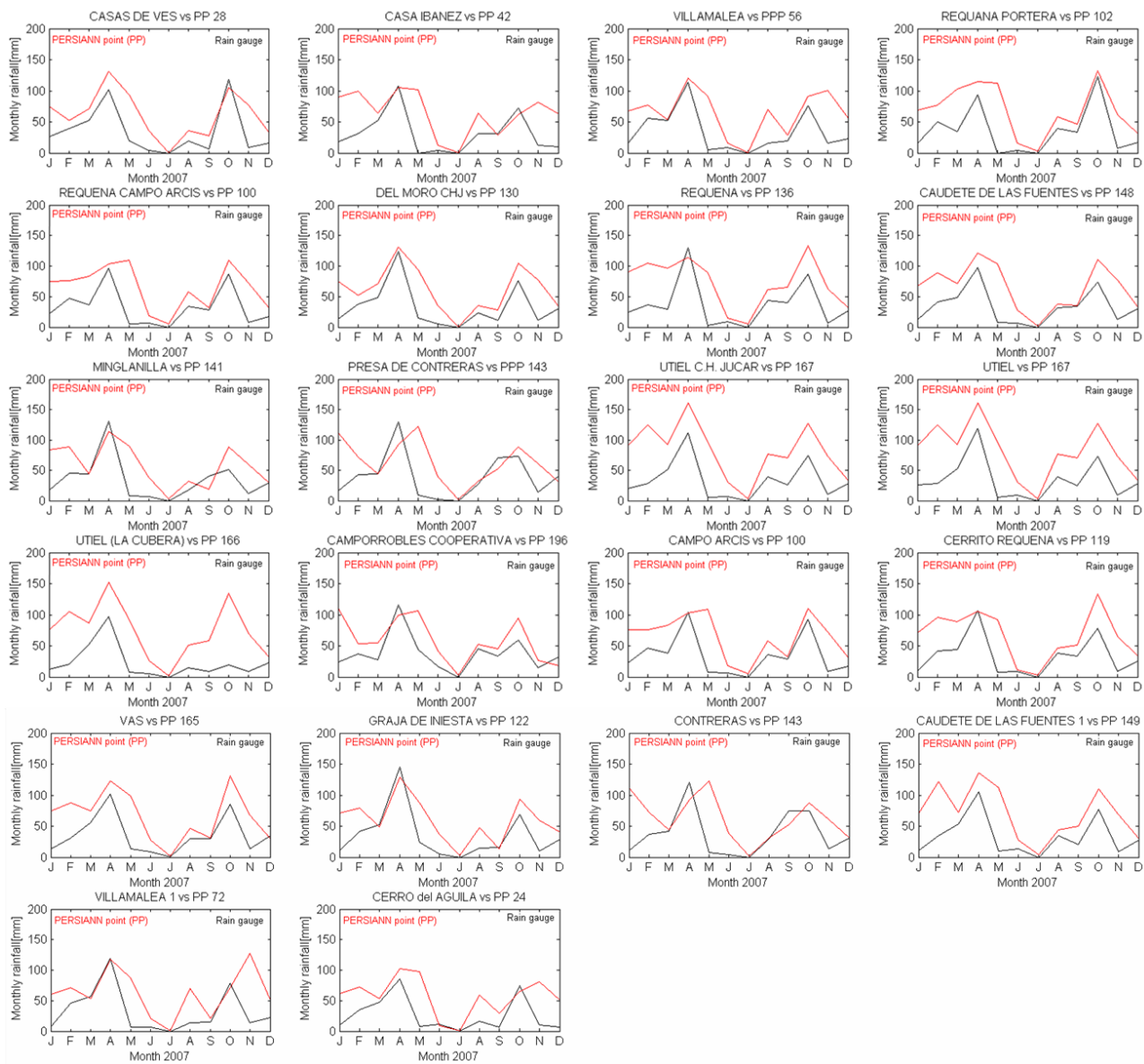
Fig. 2. Monthly comparisons between all the meteorological stations/rain gauges (black line) within the 50×50 km^2 VAS area and their nearest PERSIANN points (red lines) for 2007.
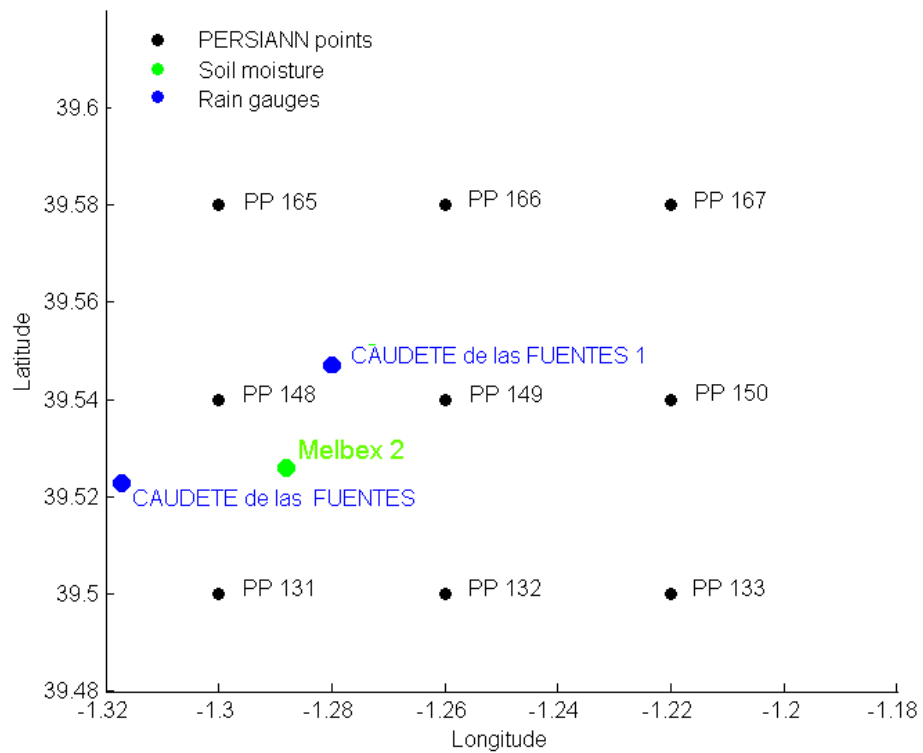
Fig. 3. Coordinates of Caudete de las Fuentes (CA FU) and Caudete de las Fuentes 1 rain gauges (blue dots) and their PERSIANN neighbors (black dots and their number of reference). The site of Melbex 2 soil moisture campaign is represented by the green dot.
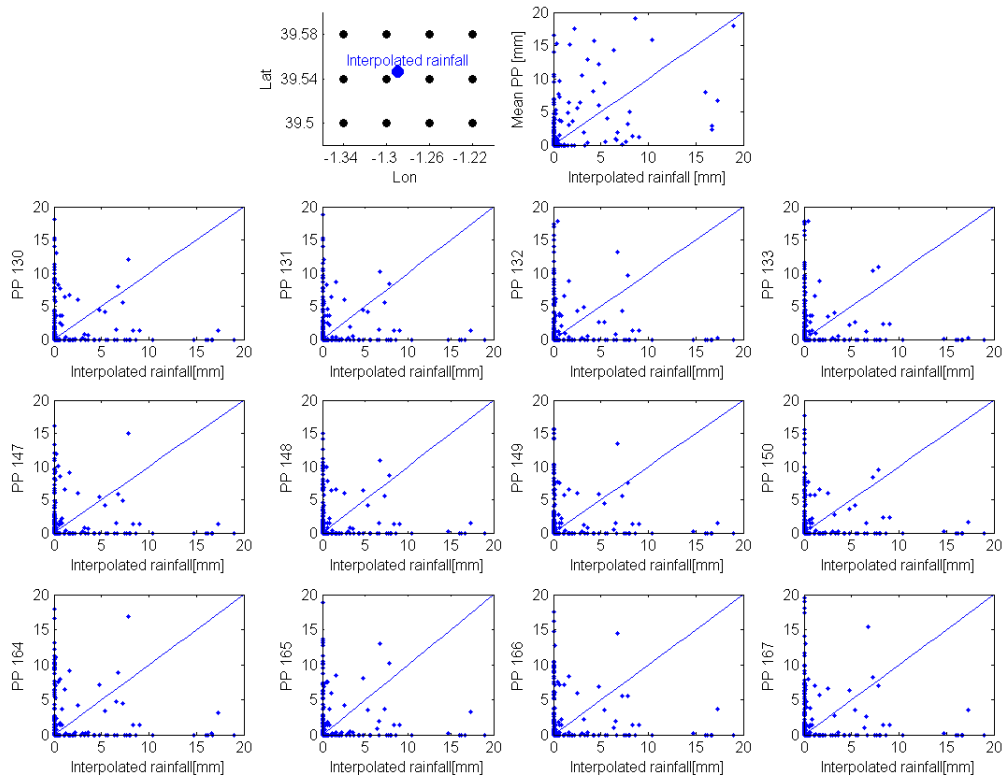
Fig. 4. Comparison between interpolated rainfall product (X axis) and PERSIANN points (Y axis). The interpolated rainfall is representative over a $10 \times 10 \, \text{km}^2$ area and is obtained using in situ observations over VAS. The mean PP represents the spatial average of the 12 PERSIANN points available within the same grid as the interpolated rainfall. The top left figure provides a map (longitude X axis, latitude Y axis) representing the interpolated rainfall and the PERSIANN points, while the top right figure represents the comparison between the interpolated rainfall and the PERSIANN mean. The 2nd, 3rd and 4th rows present comparisons of the interpolated rainfall (X axis) and each PERSIANN point (Y axis). The analysis is done for 2007 at a daily scale.
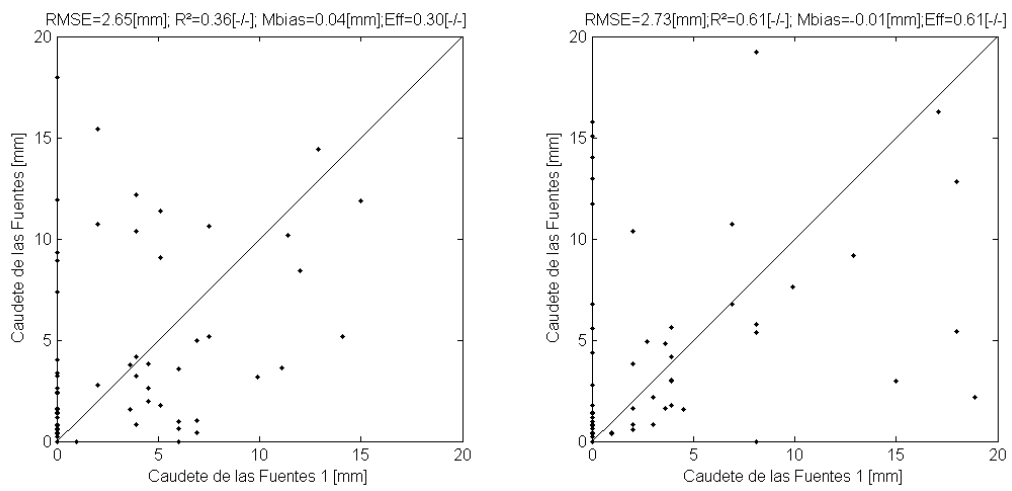
Fig. 5. Precipitation events at Caudete de las Fuentes (Y axis) versus Caudete de las Fuentes 1 (X axis) rain gauges for 2006 (left hand figure) and 2007 (right hand figure). See Fig. 3 to localize both gauges.
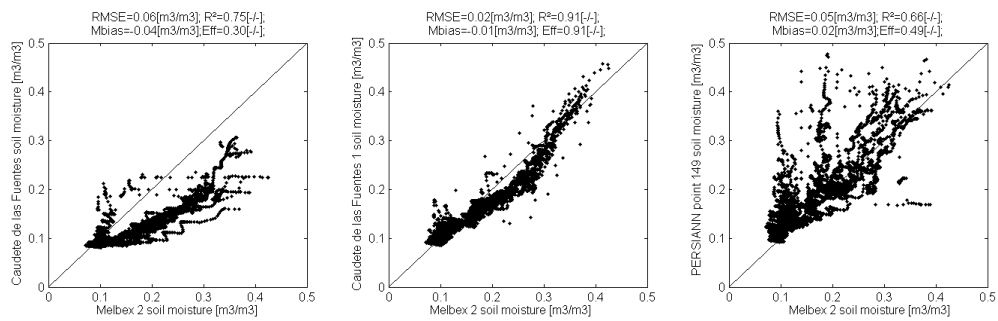
RMSE=0.06[m3/m3]; R²=0.75[-/-];
Mbias=-0.04[m3/m3];Eff=0.30[-/-];

RMSE=0.02[m3/m3]; R²=0.91[-/-];
Mbias=-0.01[m3/m3]; Eff=0.91[-/-];

RMSE=0.05[m3/m3]; R²=0.66[-/-];
Mbias=0.02[m3/m3];Eff=0.49[-/-];

Fig. 6. Simulated soil moisture at 5 cm depth using Caudete de las Fuentes rain gauge (Y axis, left hand figure), Caudete de las Fuentes 1 rain gauge (Y axis, middle figure) and the PERSIANN point 149 (Y axis, right hand figure) compared to Melbex 2 in situ soil moisture (X axis) from the 1 June to 31 December 2007.
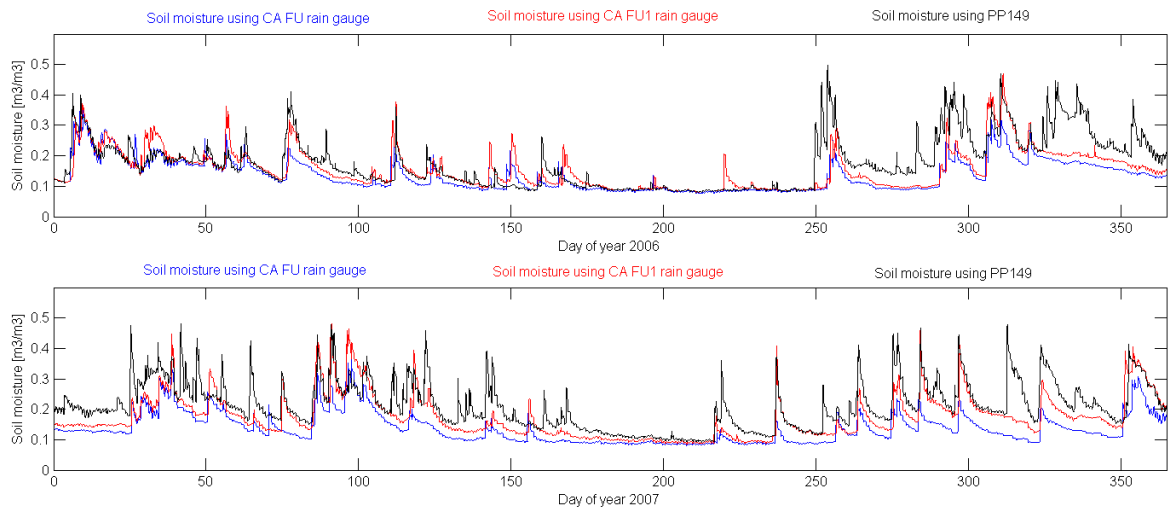
Fig. 7. Comparison between simulated soil moisture at 5 cm depth using Caudete de las Fuentes rain gauge (blue line), Caudete de las Fuentes 1 rain gauge (red line) and the PERSIANN point PP149 (black line). The comparison is made for 2006 (upper figure) and 2007 (bottom figure).
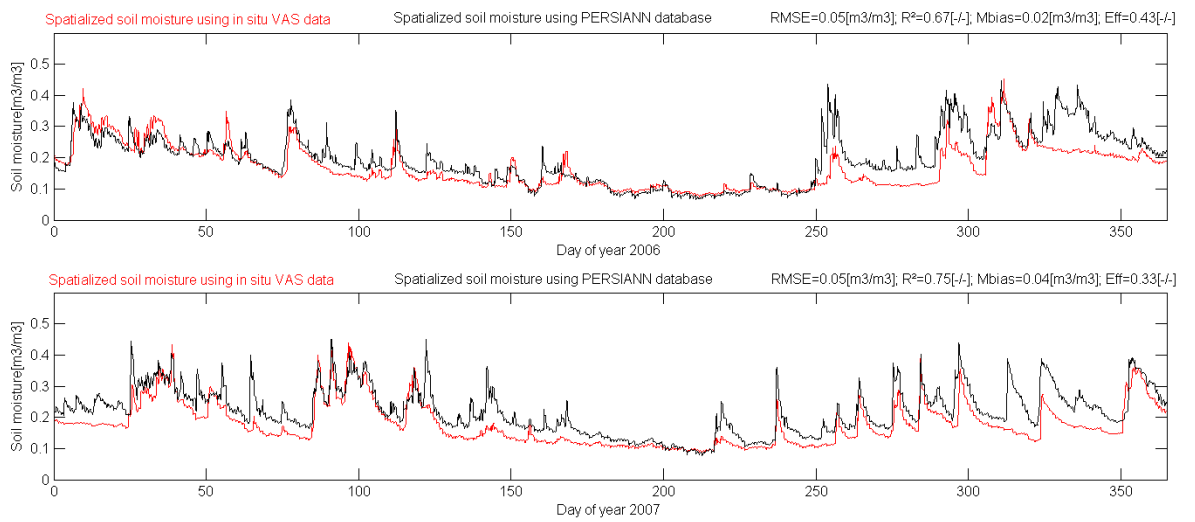
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Fig. 8. Comparison between spatialized soil moisture databases obtained using in situ observations from VAS area (red line) and the PERSIANN satellite rainfall estimates (black line) for 2006 (upper figure) and 2007 (bottom figure).
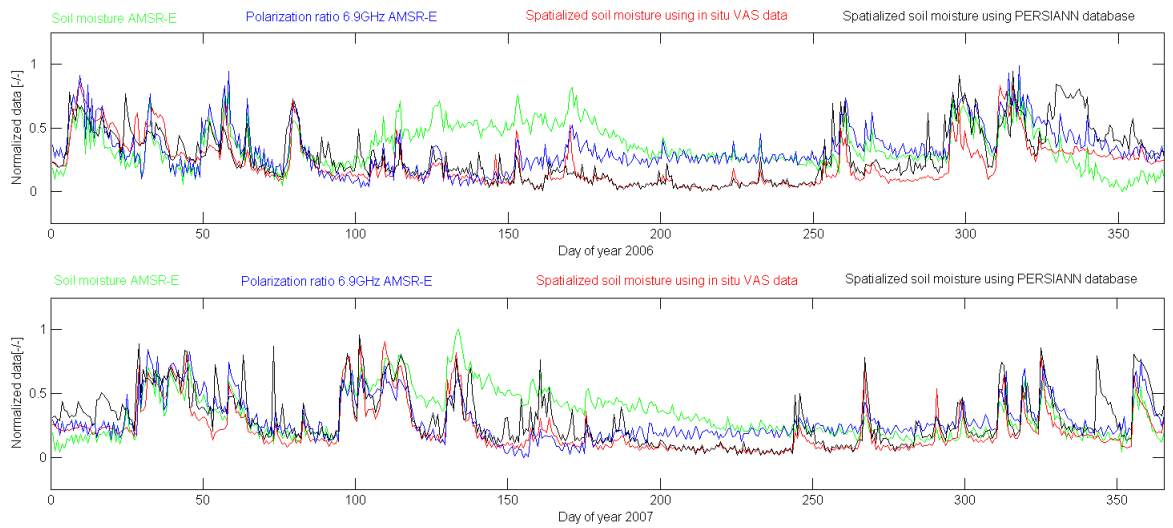
Fig. 9. Comparison between spatialized soil moisture using in situ observations(red line), spatialized soil moisture using PERSIANN datadase (black line), AMSR-E soil moisture product (green line) and AMSR-E polarization ratio at 6.9 GHz (blue line). The comparison is made for 2006 (upper figure) and 2007 (bottom figure). The data are normalized between [0, 1].